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LIGHT-HOUSE BOARD.

MEMOIR

UPON THE STABILITY

OF THE

LIGHT-HOUSE IN COURSE OF CONSTRUCTION

AT

BELLE ISLE.

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MEMOIR

UPON THE STABILITY

OF THE

LIGHT-HOUSE IN COURSE OF CONSTRUCTION

AT

BELLE ISLE.

BY LEONOR FRESNEL,

ENGINEER IN CHIEF OF THE ROYAL CORPS "DES PONTS ET CHAUSEES," SECRETARY OF THE COMMISSION OF LIGHT-HOUSES.

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STABILITY OF BELLE ISLE LIGHT HOUSE (OCEAN.)

Scale 1/100

Note. *This Plate presents the vertical Section and Plans of the different towers and high Chimnies the stabilities of which are compared in the text with that of Belle Isle Light House. The numbers are in feet.*

Chimney of Foundaries and Forges of Mans.

Column of Boulogne

Chimney of the salt refinery of Ars (Isle of Rhé)

Chimney of the Steam Engine of the Docks of St Ouen.

Chimney of the ars factory in the Faubourg at Montmartre

Fig 6 Fig 7 Fig 8 Fig 9 Fig 10

Light House of Genoa

Belle Isle Light House

Signal Tower of L'Orient

Pilier Light House near Nourmoutier

Planier Light House near Marseilles

Fig 1 Fig 2 Fig 3 Fig 4 Fig 5

MEMOIR

UPON THE STABILITY

OF THE

LIGHT-HOUSE IN COURSE OF CONSTRUCTION

AT

BELLE ISLE.

The project proposed in 1825 by Augustine Fresnel, my brother, for the light-house of Belle Isle, and approved in 1827, has appeared to the engineers charged with its execution, to need divers modifications designed to increase the stability of this edifice against the action of the winds. These engineers have presented several memoirs on this subject, which have been submitted to the commission of light-houses, and to the general council of bridges and roads. I will not attempt here to offer a complete analysis of the discussions of which these memoirs have been the object, as it would embrace a great many details of an entirely local interest. In determining to treat anew the questions relating to the stability of the Belle Isle light-house, I have thought that I ought to disengage them as much as possible from all discussion of specialities, in order to consider them only in such relations as have appeared of a nature to interest constructors. In this view, I have kept myself closely to the facts, seeking information from experience by different comparisons between the light-house in question and several edifices of the same kind. I will urge those comparisons in which I have taken successively for objects. (See *Plate.*)

The signal tower of L'Orient, fig. 1.
The great light-house of Genoa, fig. 2.
The light-house of the Pilier, near the island of Noirmoutier, fig. 4.
The Planier light-house, near Marseilles, fig. 5.
The column of Boulogne-sur-mer, fig 6.
The chimney of the salt refinery of the village of Ars, isle of Ré, fig. 7.
The chimney of the forges of Alais, fig. 8.
The chimney of the steam engine of the dock of St. Ouen, near Paris, fig. 9.
The chimney of the gas works of the Faubourg Montmartre, fig. 10.

But before entering into the details relating to the composition and stability of these different towers, I must present some general considerations upon the action of the winds, and show briefly the principles which have served as the basis of my calculations.

It appears that hitherto but little attention has been paid to the determination of the limit of the pressure exerted by the wind against edifices. It would seem, however, that this research ought to have fixed the attention of architects who rival each other in boldness in the construction of the high chimneys of forges and steam engines. It is true, that in our climate we rarely have examples of edifices of masonry overturned by the wind, and that the damages which occur proceed more commonly from some faults in the construction. However, it must be acknowledged that the effort of the wind acting upon works of masonry, still new and with little homogeneousness, has, under certain circumstances, determined or hastened their destruction, by causing or increasing unequal settling. It is then interesting, under several aspects, to study this action, and to appreciate its effects.

We know that all towers isolated, and of rather a light construction, experience in tempests oscillations analogous to the swaying of trees. These oscillations evidently result from the elasticity of the body of the edifice and the intermission of the wind. Those which I have had occasion to observe have appeared to me to succeed each other at intervals of one or two seconds. Besides, they were not accompanied by any of those tremors or rapid vibrations which the shock of a hard body, or of the waves, could have produced. I will add, that an attentive examination of several high towers exposed to frequent gales, has not enabled me to discover any trace of damage which could be attributed to these oscillations. Some constructed nearly wholly of rubble, and covered with a layer of mortar, like those of Genoa and L'Orient; others constructed of cut stone, like the tower of Corduan, and the column of Boulogne, have shown no horizontal fissure either in the mortar covering or in the joints. Hence, we must conclude that their oscillations have caused no permanent derangement in their elements, for, however small such an effect may have been, it could not have been manifested at every storm without involving the ruin of an edifice exposed for three centuries, like the tower of Genoa, to the sudden tempests of the coasts of the Mediterranean.

It must be acknowledged in the second place, that the amplitude of these oscillations has been inconsiderable in proportion to the height of the towers, since the inflexion has not been great enough to form visible fissures. Besides, it is easy to conceive how the total resulting effect of the pressure of the wind may become sensible at the top of an edifice, and the elimentary efforts not be appreciable. But, admitting this assimilation of high towers to elastic rods subject to a pressure distributed over their whole length, it may be asked why these edifices by virtue of their elasticity are not subject at intervals to destructive vibrations caused by the sudden stoppages of the winds which characterize storms? To this it may be answered, that the instantaneousness of these stoppages or changes in the direction of the wind is far from being absolute. The elasticity of the air is, in fact, incompatible with such a phenomenon, and hence it cannot be supposed that the wind, blowing even in sudden tempests, can act upon edifices submitted to its effort in the same manner as would a solid body or incompressible liquid from which they might receive shocks. In fine, all well observed facts appear to demonstrate that the oscillations impressed by tempests on masonry towers cannot injure these edifices if they are properly built, unless they are wanting in stability—that is, unless they could be overturned in mass by the effort of the wind.

We know that the effort exerted by the wind upon an immovable body is the sum of two pressures—one, the resultant of the direct action of the air upon the face against which it impinges, the other, due to the rarification of this fluid upon the opposite face. Now, according to an experiment reported by Smeaton, and cited by M. Hachette in his treatise on machines, a plane surface, having an area of one square foot, placed perpendicular to the direction of a wind, the velocity of which is twenty feet per second, experiences a total pressure equivalent to one pound. The designer of the Belle Isle lighthouse, admitting this fact, has also taken as the limit of the greatest velocity of the wind 164 feet per second, which exceeds by one-ninth the velocity of the greatest storms mentioned in the annual of the bureau of longitudes. (Year 1818.) By the help of these constants, and supposing the total pressures proportional to the squares of the velocities, he has been led to estimate the total pressure corresponding to a velocity of 164 feet per second at 507 lbs. per superficial yard.

The results of experiments analyzed by M. Navier in his notes on the hydraulic architecture of Belidor, lead to a result a little different from this.[1] I have thought consequently that I might attach it to my calculations, more particularly as I have considered the discussion of absolute stability as merely a secondary object.

In order to apply this constant to the determination of the stability of a monolithic tower having the form of a right prism with a square base, we must multiply the area of one of its faces in square yards by 507 lbs., and this product multiplied by the semi-height of the prism will give the moment of the effort of the wind. We also obtain the moment of the resistance, by multiplying the total weight of the tower by the half breadth of the base. Dividing this second moment by the first, we will obtain the expression for the *absolute stability* of the edifice with respect to the action of the wind.

In this estimate we do not take account of the diminution of resistance arising from the flexure of the tower, but in addition to the want of the constants necessary to determine the deviation of the sum-

[1] The resistance of an immovable body plunged in a fluid in motion, may be represented by the formula S D h $(m + q)$ in which S represents the area of the surface acted upon, D the weight of a cubic yard of the fluid, h the height due to the velocity of the fluid in yards, and $m + q$ a co-efficient whose first term depends on the pressure exercised upon the front surface of the body, and whose second term q answers to the negative pressure upon the opposite face.

Experience having demonstrated that the co-efficient $m + q$ varies with the form and dimensions of the body, it can only be determined with some exactness for each application from results obtained in analogous circumstances. Among the different experiments of Dubuat, we may admit as applicable to square edifices that which concerns the action of a fluid upon a cube, and according to which we have $m + q = 1.457$.

I will suppose the air at the temperature of melting ice, when the weight of a cubic yard is 2. 1919 lbs.

I believe that I thus take an extreme case, for I do not think that in our climate we ever have very violent storms at a temperature below 32° Fahrenheit.

The height h due to a velocity of 164 feet, being also 139 yards, we will have for the total pressure per square yard, calculated without regarding the compressibility of the air :

lbs $2.1919 \times 1.457 \times 139 = 444$ lbs.

But according to an experiment of Hutton, cited by M. Navier, this result ought to be augmented about one-sixth on account of the increase of the density of the air by the effect of the resistance. We will then have

$$P = 518 \text{ lbs.}$$

a total pressure which only differs one-forty-sixth ($\frac{1}{46}$) from that indicated by A. Fresnel.

(See *the Principles of Hydraulics, by Dubuat, the Notes of M. Navier upon the Hydraulic Architecture of Belidor, and the Work of M. Coriolis upon Machines.*)

mit, it is evident that it can be left out of consideration without altering the relations which are the essential object of this memoir.

The square monolithic tower that I have just taken for an example, offers the simplest case of calculations of this kind, both on account of its shape and the disposition of the plane of rupture. Ordinarily we have to consider edifices composed of numerous layers of masonry whose adhesion has the greater influence upon the stability as the sizes of the materials entering into the construction are smaller. If we suppose this adhesion zero in a tower formed of layers sub-divided into brick headers and stretchers, rupture under the effort of the wind ought not to take place horizontally. It should take place, as in sustaining walls, along an oblique section whose inclination would be determined by the condition that the ratio between the effort of the wind and the moment of the weight of the solid above this section, should be a maximum. But we may observe that in the majority of high towers, the adhesion of the mortar and the disposition of the materials are such that the section of rupture must be less inclined than it is in common sustaining walls. We add, that the results of the comparisons between the different edifices previously cited, will not be sensibly affected by the hypothesis that the sections of rupture are horizontal. We may, therefore, without inconvenience, admit this hypothesis, which averts a useless complication of calculations.

The determination of the *point of most easy rupture* presents again a problem of *minima*, the direct solution of which would generally exact very long calculations; [2] but fortunately the position of this

(2) Let us take for example a tower of homogeneous construction, having an outside truncated conical surface, and an inside cylindrical open space with the same vertical axis as the outside surface.

Call a the radius of the base of the inside cylinder;

b the thickness of the top course;

n the slope per unit of the exterior profile;

x the vertical distance from the plane of rupture to the top of the tower;

r the radius of the section corresponding to the plane of rupture;

h the distance of the centre of pressure above the plane of rupture.

For the present investigation, we may, in the expression for the stability, leave out the constant co-efficient which is the ratio of the weight of a cubic yard of masonry, and the weight representing the reduced pressure exercised by the wind upon a square yard of the conical surface measured on its vertical projection. Then the three quantities representing the moments of the resistance, of the pressure, and the absolute stability, will be replaced by the following, viz:

point in the majority of cases will be manifested at the first glance, so that it can easily be determined by a few trials of false positions.

If we wish to apply these principles to the calculation of the stability of a round tower, we find ourselves arrested at once by the difficulty of appreciating the effort exerted by the wind upon the surface of a cylinder. In the absence of empirical formulæ based upon sufficiently numerous experiments, I have considered one of the elementary pressures acting upon the front face of the cylinder, and I have determined by a double decomposition along the tangent to the circular section, and along the diameter perpendicular to the direction of the wind, the value of the component tending to overturn the obstacle. I have thus been led to admit that the action of the wind

The first, by the product R of the volume V of the masonry multiplied by the radius r of the section of rupture.

The second, by the product P of a meridian section of the tower, by the ordinate h of the centre of pressure.

The third, by the quotient S of the first divided by the second.

Making, in order to simplify the notation—

$a + b = p$, and $2a + b = q$, we will have:

$$S = \frac{R}{P} = \frac{Vr}{h\ (2\ a + 2\ b + nx)\ x} =$$

$$\frac{\pi\ [3\ b\ p\ q + 3\ (p^2 + b\ q)\ nx + 4\ p\ n^2\ x^2 + n^3\ x^3]}{3\ px + nx^2}$$

h being equal to $\frac{x}{3}\left(1 + \frac{a + b}{2\ a + 2\ b + nx}\right)$

Whence we deduce the following equation corresponding to the minimum value of S:

$$x^4 + \frac{6\ p}{n}\ x^3 + \frac{3\ (3\ p^2 - b\ q)}{n^2}\ x^2 - \frac{6\ b\ p\ q}{n^3}\ x - \frac{9\ b\ p^2\ q}{n^4} = o \ldots\ldots (A)$$

To apply this to the determination of the plane of rupture of the tower of Belle Isle, I will suppose this edifice freed from its outside basement work, from its staircase, its interior arches, its capital, its lantern, and from the parapet wall under the lantern. Hence we shall have from *Fig.* 3—

$a = 2.296$ *yds.* $b = .710$ *yd.* $n = .0171$ $a + b = p = 3$ *yds.* $2\ a + b = q = 5.3$ *yds.*

$$\frac{1}{n} = 58.3.$$

These values substituted in equation, (A,) give

$$x^4 + 1049\ x^3 + 236940\ x^2 - 13421850\ x - 3521187745 = 0.$$

From which we obtain $x = 117$ *yds.*

Hence we may conclude that the plane of rupture would descend to the level of the foundation, if the outside basement work were suppressed.

upon a vertical cylinder is reduced to two-thirds of that which it would exercise upon the meridian section of the same cylinder. (3)

This result, the degree of approximation of which can only be determined by some direct experiments, I have used to compare the stability of the round tower of the Belle Isle light-house with that of the square tower of the Genoa light-house, of the chimneys of the salt refinery of Ars, of the steam engine of the dock of St. Ouen, and of the gas factory of the Faubourg Montmartre.

Comparisons of this kind present, I must confess, several causes of uncertainty ; but fortunately we can avoid all difficulty, by only comparing edifices which have nearly the same form, and which do not present too great differences in their principal dimensions. Thus we will compare the cylindrical tower of Belle Isle with a circular edifice like the light-house of the Pilier, the column of Boulogne, or the chimney of the forges of Alais ; and the square tower of Genoa will be compared with the quadrangular towers of the dock of St. Ouen, or of the gas factory of the Faubourg Montmartre.

Without pressing further these preliminary considerations, which appear to me to suffice for the applications which I have had specially in view, I pass to the calculation of the stabilities of the different

(3) Call f the force of the wind ;

r the radius of the cylinder ;

a the angle formed by the direction of the wind with the meridian plane corresponding to the point of application of the force f.

The double decomposition spoken of above will give for the value of the component of f tending to overturn the cylinder—

$$f \cos^2 a \, dx = \frac{f \, dx}{1 + \frac{dy^2}{dx^2}} = \frac{f \, (r^2 - x^2) \, dx}{r^2}$$

and integrating this expression between the limits $x = r$, and $x = -r$ we shall have for the total pressure upon the semi-cylinder exposed to the wind—

$$P = \frac{4}{3} r \, f,$$

a value about one-sixth below that which the author of the design of the Belle Isle light-house used to obtain the results contained upon the second sheet of the lithographic plates of that design.

It seems to result from some experiments of Bossut upon cylindrical prows, that the pressure of the wind upon a cylinder would only be one-half of what it would be on a meridian section ; but I have not thought that I ought to avail myself of this value, as it is too remote from the hypothesis admitted by the author of the design.

edifices previously mentioned, commencing with the Belle Isle light-house.

Belle Isle light-house. (Fig. 3.)

According to the design originally adopted in 1825, the tower of Belle Isle light-house was to be constructed as a hollow column 172.24 feet in height, with an exterior diameter of 23.95 feet at the base reduced to 18.04 feet at the top. Its interior diameter was fixed at 13.78 feet. The lower part of this column was to be surrounded for a vertical height of 31.16 feet with a circular outside basement, with two stories, and 45.92 feet in diameter. The exterior wall of this basement was joined to the column by six partition walls.*

Two arched chambers, comprising together a total height of 26.25 feet, occupied the upper part of the tower. Its platform was surmounted by a cylindrical parapet wall 7.22 feet high and 13.12 feet exterior diameter, designed to receive a lantern 11.48 feet in diameter, and 9.84 feet high, a dome nearly hemispherical not included.

Between the entrance story and the first chamber at the top of the tower, there was to be an open-work circular staircase, having a circular well 7.22 feet in diameter.

The whole of the masonry was to be of cut granite, except the foundation, designed to be of rough blocks, and some arches to be of brick.

The mortar was to be made of the common lime of Nantes.

It was known that at a short distance below the surface of the ground from several points examined, a schistose rock was present upon which the foundations of the most elevated edifice might be safely placed, particularly on the site finally adopted, which is elevated more than 125 feet above the level of high water.

Since its approval, this design has been several times brought to the notice of the council des ponts et chaussées on account of several modifications instigated (provoquées) successively by the engineers charged with the direction of the work.

* The principal arrangements of this basement have been suggested to the author of the design by M. Tarbé de Vaux-Clairs, Inspector-General des Ponts et chaussées, member of the commission of light-houses.

These modifications consist of—

1. The addition of a partition wall to the large open circular staircase.
2. The addition of six large exterior counterforts.
3. The addition of a mass of masonry about 5.6 feet thick below the helicoidal solid formed by the staircase.
4. The employment of iron cramps to join the stones of each course to each other.

The increase of expense resulting from these modifications, was to be about forty thousand dollars.

It is essential to observe, that in all this, the only question was to obviate presumed dangers, and not to remedy known damages; for at the date when the last modifications proposed were examined, (July 1831,) the works executed at the Belle Isle light-house had only reached a height of about 23 feet above the entrance story.

The addition of the partition wall was designed less to consolidate the tower, than to consolidate the winding staircase, and to render its construction easier.

It is from this point of view, at least, that the question was viewed by the general council "des ponts et chaussées," when it adopted this modification. The thickness of the partition wall, at first fixed at 0.98 feet, was in the end increased to 1.97 feet, in conformity with a report of M. Lamblardie, Division Inspector.

As to the employment of counterforts, and the increased thickness of the inclined mass of the staircase, these modifications were proposed only to increase the stability of the projected tower, so that it should at least equal that of the signal tower of L'Orient. This last term of comparison had particularly attracted the attention of the engineers of the Belle Isle light-house. In fact they considered the tower of L'Orient as one of the boldest edifices among all those which exist upon our ocean coasts, at least in localities similar to that of Belle Isle, with respect to the violence of the winds to which they are exposed.

The employment of full counterforts is generally of little advantage as a means of increasing the resistance of a tower against the action of the wind, whilst the additional masonry presents a great surface in proportion to its mass; but it must be remembered that the works already executed at the Belle Isle light-house permitted no other method of obtaining the degree of stability considered necessary, for a large increase of the exterior diameter of the tower would have

reduced the rooms of the circular basement, so that they would only have been simple passages.

The extra thickness proposed for the inclined mass of the staircase could only increase the stability of the tower on account of the weight it added to it. But, admitting the necessity of this increase of stability, it might be feared that such a mass of masonry built in an inclined position, would eventually prove more hurtful than useful to the solidity of the edifice.

The employment of iron cramps was proposed as a means of preventing the effect of the concussions of nature in leading to the separation of the stones in the same course. Now from the observations cited above such an effect cannot be feared for the Belle Isle tower, which will not be exposed to the shock of the waves like the Eddystone, Bell Rock, and Le Four light-houses. Besides it is evident that this system of cramps, adding nothing to the adhesion of the layers to each other, would not sensibly increase the stability of the tower against the action of a horizontal force tending to overturn it.

The arrangement of the two flat arches of the upper rooms of the tower appeared subject to some inconveniences, and it has been judged proper to substitute iron platforms for them. I will observe with regard to this, that it is desirable to avoid the employment of every kind of iron work in edifices exposed to the destructive action of sea air. I therefore would not hesitate to prefer, in the case in question, brick arches to iron platforms. I must acknowledge, however, that the renewal of these platforms will present but little difficulty, so that my observation here has for its object a question of economy, rather than one of art.

In fine, the modifications of the design of A. Fresnel for the Belle Isle light-house definitely adopted, are reduced to the addition of a partition wall 1.97 feet thick, having an interior void 4.92 feet in diameter, and in the substitution of two iron platforms for the two flat arches in the upper part of the tower.

For the calculations relating to the stability of this edifice, I have admitted with the author of the design—

1. That the point of easiest rupture would be situated at the level of the roof of the basement, except in the case where I have left out of consideration the partition walls, the rooms of the basement, and the platform which covers them ;

2. That if the tower were to yield to the effort of the wind, there would be crushing over the edge of rotation, so that the arm of lever of the resistance instead of being equal to the radius of the section of rupture, that is to 11.45 feet, would be reduced to 9.84 feet. (4.)

3. That the cubic yard of masonry of cut granite weighs 4552.5 lbs.

I have also calculated the additional stability due to the partition wall of the modified design, considering this interior tower as making one body with the principal tower, at least at the instant which would immediately precede the fall of the edifice. In other words, I have admitted that the additional stability would be proportional to the weight of the partition wall.

The weight 4552.5 lbs. attributed to the cubic yard of granite masonry is perhaps a little large; but I have applied it also to the marble of the tower of Boulogne, and I have taken care to take the maximum in the determination of the weights of the other edifices taken for terms of comparison.

From these bases, and the mode of calculation which has just been explained, I have found for the tower of Belle Isle, considered under different hypotheses, the following stabilities:

1. Design first approved.(5.) 4.9
2. With partition wall 0.98 feet thick, and 6.56 feet interior diameter 5.3
3. With partition wall 1.97 feet thick, and 4.92 feet interior diameter 5.8
4. With full newell 8.86 feet in diameter, comprising a filling up with rubble masonry 4.92 feet in diameter 6.2

Finally, admitting the suppression of the six partition walls of the basement and that of the platform, I have found for the stability of the column, considering its whole height 5.2

Thus then the tower of Belle Isle, finished according to the first design, would have presented a stabitity equivalent to nearly five times the effort of a storm capable of exerting a pressure of 507 lbs. per square yard, and the addition of a partition wall 1.97 feet thick, will only increase this stability about one-fourth.

I am far from despising the facilities for the construction of the staircase which the introduction of the partition wall will add, and the increase of solidity to this part of the edifice which will result from it. But, on the other hand, I will observe with the author of

(4.) To follow this hypothesis in all its consequences it would be necessary to admit a deviation from the vertical of 1.60 feet, and to add to the moment of the pressure of the wind the moment of the weight of the masonry beyond the vertical; but we would then be too far from the conditions of equilibrium considered at the instant which would immediately precede the fall of the tower.

(5.) Weight of the column above the basement, 983.6 cub yd. $\times$ 4552.5 $=$ 4477839 lbs.
Moment of the horizontal resistance 4477839. $\times$ 3.28 $=$ 14687312.
Moment of the pressure exerted by the wind $\frac{2}{3} \times 507 \times 8806. =$ 2976458.
Ratio of the moments of resistance and pressure, or stability $=$ 4.9

the design, that admitting the insufficiency of the penetrations of the steps into the wall of the tower to render the stability of each step independent of that of the others, we might have, as in the staircase of the tower of Cordouan, consolidated the system by landings placed at certain distances. We could thus have prevented the inconveniences arising from fearing the solidity of the 266 steps of the grand circular staircase, without sacrificing the happy effect, and the real advantages for the service, which the projected system would have offered. Moreover, it cannot be denied that these considerations ought to have appeared of little importance, when the stability even of the edifice has been placed in doubt, and without doubt, it was necessary to make some concessions to fears so grave. We remark, besides, that in deviating from the combination according to which the hollow void of the partition wall would have been filled with masonry, we have assured ourselves of the maintenance of an important advantage, that of being able to raise the building materials in the interior of the tower.

In the comparisons which are to follow, I shall suppose the Belle Isle light-house built in conformity with the arrangements definitely adopted, so that, when I speak of the stability of this edifice, it must be understood that the tower, with the partition wall 1.97 feet thick, and having a stability equivalent to 5.8, is refered to.

Signal tower of L'Orient. (Fig. 1.)

The signal tower of L'Orient was constructed in 1785 by M. Guillois, engineer, upon the highest point in that city, 65.61 feet above high water. The edifice presents the form of a truncated cone 122.56 feet high, 23.44 feet in diameter at the base, reduced to 13.84 feet in diameter below the capital.

The staircase with full newell occupies a cylindrical well 11.25 feet in diameter. The diameter of the newell is 1 foot. Upon the platform of the tower a room of wood is placed, from the middle of which a signal mast is raised.

The body of the tower is built of rubble masonry, with chain courses, plinths, base, and capital of cut granite. This mixed system, applied to so elevated an edifice, might entail the greatest inconveniences, in spite of the thickness of the masonry, and the great inclination of the exterior walls; but these have been avoided by the

great care taken in the construction of all parts of this tower. So the oscillations which it must experience in tempests have not produced any fissure neither in the cut stone masonry, nor even in the joints of the rubble stone sides. From its base, it towers over all the edifices of the city, and on the side towards the sea in the direction of the prevailing winds remains entirely unmasked.

It is evident that the thickness of the masonry might have been much reduced, if the edifice could have been entirely constructed of cut stone. There would have resulted, it is true, an apparent diminution of stability with respect to the efforts of the wind, but the unfortunate chances attached to the adoption of the mixed system of rubble masonry and chain courses of cut stone would have been avoided.

The effects of unequal settling were much more to be feared for the tower of L'Orient as it has been built, than was the action of the wind perhaps for that of Belle Isle; and, in fine, the first structure, although superior in horizontal stability, appears bolder to me than the second.

Applying to the tower of L'Orient the method of calculation previously explained, and taking 4552.5 lbs. for the weight of the cubic yard of cut stone masonry, and 3372.3 lbs. for that of a cubic yard of rubble masonry we find for its stability 7.4.[6] So that it only exceeds by one-third the stability of the Belle Isle tower.

We might have expected a much greater difference from a first glance at the comparative sections of the two edifices; but this result is easily explained by the ratio between the specific weights of rubble and cut stone masonry.

Light-house of Genoa. (Fig. 2.)

The light-house of Genoa is, after that of Cordouan, the most remarkable among all those which are exclusively devoted to the lighting of seacoasts. It is elevated at the extremity of the promontory of San Benigno upon a mass of rocks 128 feet above the level of the sea. Its

(6) Weight of tower $= 167.4 \times 4552.5 + 897.4 \times 3372.3 = 3788609$ lbs.
(cubic yards. cubic yards.)
Moment of horizontal resistance $3788609 \times 3.379 = 12801709.8$.
Moment of the pressure exerted by the wind $\frac{2}{3} \times 507 \times 5110.9 = 1727490.9$.
Ratio of the moments or stability $= 7.4$.

plan is square. It presents the appearance of two towers, one placed above the other, the lower 108.92 feet high and 29.53 feet square, and the upper 97.77 feet high and 22.97 feet square. The upper platform is crowned by a small round tower 11.48 feet high and 20 feet in diameter, upon which is raised a lantern 11.81 feet in diameter and 18.37 feet in height, including a hemispherical dome. The thickness of the principal walls is about 6.5 feet in the lower story, and about 3.25 feet in the upper story.(7) These two stories are divided, the first into four, and the second into three chambers, by seven flattened arches. Light wrought iron cramps counteract the thrust of these arches, according to the system generally adopted in Italy.

The staircases, disposed laterally, are of light construction, and add very little to the stability of the edifice. The steps are formed of schistose slabs.

The masonry, except the cornices and balustrades, is rubble or large schistose blocks, with interior revetments of brick in a few places only. The exterior walls are covered with a coating of mortar made of lime and sand.

The success of this great construction must above all things be attributed to the excellence of the mortar. And we see that here, the most imminent danger does not proceed from the action of the winds, but from the more or less regular settling in an edifice where rubble masonry for the greater part nearly unwrought, is found piled to a height of about 220 feet.

For the want of precise figures to determine the mean weight of the masonry of the Genoa light-house, I have taken the greatest, reckoning 3878.1 lbs. per cubic yard. I have thus found that the absolute stability of this light-house may be valued at 6.2.(8) So that it is only about one-twelfth above that of the Belle Isle light-house.

(7) I will confess that I cannot answer for the exactness of these dimensions. I have taken them from a very carefully made drawing (but not numbered) made to a scale of $\frac{1}{100}$ belonging to the archives of the commission of light-houses. According to a note of Lieut. Col. Chiodo, of the engineers attached to the fortress of Genoa, the first story of the large light-house of this city was 113.84 feet high, and the second 109.73 feet high; but it is more than probable that the parapet wall of the lantern is comprised in the second height, so that the difference between my estimate and that of Col. Chiodo, is reduced to 5.40 feet.

(8) Weight of the tower 3761.3 cubic yards $\times$ 3878.1 $=$ 14586638.6.

Moment of the horizontal resistance 14586638.6 $\times$ 4.92 $=$ 71766264.

Moment of the pressure exerted by the wind 22636.93 $\times$ 507 $=$ 11476923.51.

Stability $=$ 6.2.

With respect to the action of the wind, the tower of Genoa may at first sight appear placed under more favorable circumstances than the Belle Isle tower, which will not be sheltered on any side, whilst the first, placed at the foot of the Appenines, is sheltered for more than half of the horizon. However, observation appears to weaken this first view, for it seems fixed that the sudden storms of the Mediterranean are not at all less violent than the gales of the ocean in the same parallel, and sailors who have frequented the river of Genoa agree in stating that the sudden gales near mountainous coasts are more terrible than those in the open sea.

Pilier light-house, near the island of Noirmoutier. (Fig. 4.)

The Pilier light-house, constructed in 1827 by M. Plantier, jr., engineer, offers here a most important comparison, for its situation upon an isolated rock in the sea, one league from the northeast point of the island of Noirmoutier, appears quite identical, with respect to the frequency and intensity of the storms, to that which could have been built upon one of the highest plateaus of Belle Isle. This edifice presents the form of a column 86.27 feet high, with a base 15.09 feet in diameter, reduced to 12.04 feet below the cornice. Upon the platform is a cylindrical parapet wall 5.91 feet high, and 11.35 feet in diameter. It is surmounted by a lantern 9.84 feet in diameter, and 12.14 feet high, including a dome 3.75 feet high. The winding staircase with full newell occupies a cylindrical well 6.56 feet in diameter and 65.61 feet high.

A square building of light construction surrounds the foot of the tower. It is 45.28 feet square and 9.84 feet high, the roof, which is covered with tiles, not included. Four partition walls 1.31 foot thick, join three of the faces of the building to the body of the tower.

The thickness of the wall of this tower is 4.26 feet at the level of the ground, and is reduced to 2.95 feet at the top of the staircase. At this level there is an interior offset of 0.66 foot, and at 9.84 feet above, a second offset of 0.16 foot.

The interior space corresponding to the capital is occupied by a service chamber comprised between two iron platforms. Between the beams upon which the upper platform rests have been placed six ribs of a cast iron arch, in the key of which is fixed the support of the frame of a revolving lens apparatus.

The principal part of the body of the tower for a height of 65.61 feet has been built with cut granite for the exterior, with an interior mass of rubble. The upper part is built entirely of cut granite.

I have supposed that the point of easiest rupture was situated 13.12 feet above the ground, and I have found that the stability of the Pilier tower may be represented by the number 4.4(9)

Thus the stability of the Belle Isle light-house would exceed more than one-fourth that of the Pilier light-house, which has never been questioned. Now, admitting that there was an equality between the two edifices with regard to their resistance to the wind, there would still remain an important advantage in favor of the first, on account of its construction being much more homogeneous. I was in the Pilier light-house some months after its completion, during a storm which lasted several days and imparted an oscillating movement upon the tower, very light without doubt, but which gave one an irresistible impulse to suppport oneself against the side of the upper chamber. Since that time the same edifice has borne much more violent tempests, and no fissure has been shown in any of the masonry up to the present time.

Planier Light-house near Marseilles. (Fig. 5.)

The light-house constructed in 1827 upon the Planier rock at the entrance of the roadstead of Marseilles, has presented several circumstances interesting to study, but upon which I shall not enlarge, except when they appear to me to be attached to the special object of this memoir.

According to the design suggested in 1823, by M. Garella, engineer in chief, director, the Planier light-house was to be constructed as a round tower 69.87 feet high, raised upon a rectangular basement 26.25 feet high and 45.93 feet square. The tower or column was to have a diameter of 17.71 feet at its foot. A circular well-room 8.53 feet in diameter was reserved for a winding staircase with full

(9) Weight of the tower = 219.91 cubic yards × 4552.5 + 74.88 cubic yard × 3372.3 = 1253686.426 lbs.

Moment of the horizontal resistance 1253686.426 × 2.19 = 2745573.27.

Moment of the pressure exerted by the wind = 1837.61 × $\frac{2}{3}$ × 507 = 621112 18.

Stability = 4.4.

newell, so that the wall of the column was to be 4.59 feet thick at its base. The basement was solid as high as the level of the first floor, 9.84 feet above the rock, and contained several rooms covered with semi-circular cylindrical arches respectively parallel to the four walls of the enclosure, forming piers 3.28 feet thick. These arches, 9.84 feet in diameter, raised upon piers 11.15 feet high, were to be .98 foot thick at the key, the paving of the roof not included.

The column was to be crowned by a lantern 11.15 feet in diameter and 11.48 feet high, covered with a conical roof 3.28 feet high.

The exterior wall and the exterior staircases of the basement, as well as the coping of the cornice, were to be built of hard cut stone.[10]

The exterior of the column and its staircase were designed of a very tender limestone, and the remainder of the masonry, except the brick arches of the basement, was to be of rubble or large blocks.

The work was commenced according to these arrangements, and the basement was finished, when, in the month of March, 1825, the commission of light-houses, taking into consideration the importance of the part which the Planier light-house was to play among all those which it was proposed to light on our Mediterranean coast, decreed that the height of the tower should be made 131.22 feet.

M. Garella consulted on the subject, and appreciating all the advantage of extending the range of the light, believed that he might consent to the change without essentially modifying the economy of his design, and the construction was consequently carried on in conformity with the new programme.

It appears that the works presented no circumstance of note until the winter of 1827. At that time, fissures, and indications of settlement, began to be shown at the foot of the staircase, and were attributed in part to the oscillations impressed upon the tower by a succession of very violent gales. These damages were increased by an extraordinarily violent storm, which took place on the 18th of March of the same year.

According to the observations collected by M. Cousinery, engineer, the wind had caused the shaft of the tower to oscillate like an elastic rod, and its oscillations had produced openings or cracks in the cylindrical arches of the rooms of the basement, and several ruptures in

(10) *Magnesian limestone* from the quarries of Cassis, near Ciotat, and of the same nature as the Planier rock.

the lower part of the staircase. The upper part of the edifice presented no trace of separation.

I will observe that the increase of height of the tower had prudently been limited to 16.40 feet, and that at the time these damages were discovered, the lantern had not yet been placed, or at any rate had not been glazed.

The engineer-in-chief caused the works to be suspended, and presented a design of supplemental works, which has been as well executed as it was happily conceived. In conformity with this additional design, all the empty spaces of the lower basement were filled with masonry for a height of 14.76 feet, except a circular space 6.56 feet in diameter, reserved near the entrance door for a winding staircase. The principal staircase was also filled up for a height of 27.23 feet, and the foot of the tower was made solid 18.04 feet high above the first square mass by a second mass 23.95 feet square, in which was placed a staircase communicating with that of the tower. A second basement, 39.37 feet square and 14.43 feet high, was raised above the first, and divided into several rooms and store-rooms.

The glazing of the lantern was only placed near the end of 1828, and the lighting apparatus, placed a short time afterwards, was set in operation March 1, 1829.

As a last result, no other trace of damage to the Planier light-house was noticed, except a very light inclination of the shaft of the column, and this edifice appears now perfectly consolidated. It can be seen, too, from an inspection of *fig.* 5, that the addition of a second story to the basement detracts in no degree from the happy architectural effect of the primitive design.

The study of the facts that I have just pointed out is the more interesting as they appear to have given rise to erroneous consequences, which, perhaps, have not been without influence upon the arrangements adopted for some of the light-houses recently designed.

The design originally approved for the Planier light-house was conceived in a system of rigid economy, which, without excluding elegance of proportions, could only suit a tower of moderate height.[11]

(11) It is to be remarked that notwithstanding the importance of the additional works executed at the Planier light-house, this monument, elevated upon a rock situated three leagues at sea and often inaccessible, has only cost 70.000 frcs. This is scarcely one-third of what a similar edifice would have cost in an analogous situation upon the coast of the Atlantic.

In the first rank of the circumstances which might render the increase of height dangerous, I will cite the small tenacity of the rock employed in the construction of the principal staircase and exterior of the column. As well as I have been able to judge from a simple inspection, this rock could by no means sustain without crushing or splitting, the increased pressure which the oscillations of the column would suddenly bring upon some parts of the lower courses. Hence, the effect of these oscillations would be rapidly increased, particularly at a time when the interior mass of rubble masonry made with common lime had acquired very little consistency.

It is probable that if the mortar had been hardened when the edifice experienced a succession of violent gales, the damage would have been much less severe. Nevertheless I have been led to believe that the arches of the basement, with regard to their arrangement and lightness, in any event, would have suffered some rupture in consequence of the oscillations of the tower.

I will here remark, in this connection, that the design of the Belle Isle light-house presents more security, since the system of conoidal arches of its basement exercises no thrust against the exterior wall. I will further remark, that admitting that the Belle Isle tower, as it was designed by A. Fresnel, were bent 1.97 feet in tempests, the corresponding deviation of the platform would have been only 0.06 inches. (12)

The Planier tower, according to what has just been said, has passed through two states essentially different, which it is important to compare with respect to the stability.

In its first state, before the execution of the additional works, this edifice presented above the basement a column 86.93 feet high, not yet surmounted with its lantern. Its stability was then about 5.3.

(12) Knowing the total flexion of an elastic rod uniformly pressed along its whole length, we can deduce its deviation at any point whatever by the equation:

$$x = \frac{4\delta}{h^4}\left(\tfrac{1}{2}\,h^2\,y^2 - \tfrac{1}{3}\,h\,y^3 + \tfrac{1}{12}\,y^4\right)$$

in which h represents the height of the rod, and δ the deviation of its summit. (See *the Memoir of M. Duleau upon the Resistance of Iron.*)

If we consider the Belle Isle tower as an elastic rod 186.99 feet high, having an extreme deviation $\delta = 1.97$ feet, and make y equal to the ordinate of the platform of the basement, that is to say, 31.17 feet, we will have for the deviation at the level of that platform—

$$x = 0.06 \text{ inches.}$$

At present, the column of Planier is only 71.35 feet high above the raised basement, but it is surmounted with its large lantern, and its stability is reduced to 4.6.[13]

This singular result, which I had foreseen before I was able to collect all of the documents necessary to verify it by calculation, confirms the views I have just presented upon the different causes of the damage experienced in the construction of the Planier tower. In fact, if the damage had only been caused by the insufficiency of the weight of the masonry of the tower, the additional works would have in no degree attained their end, since the column topped with its lantern has been found, notwithstanding the reduction of the height of its shaft, to have lost more than one-eighth of its original stability. But independent of the gradual hardening of the mortar, which has sensibly increased the elastic force of this column, the crushing of the lower courses of the tower has been arrested by the masonry filling of the basement rooms, whence it has resulted that the edifice, although less *stable* at present, at least in appearance, has in fact gained a great deal in *solidity*.

The stability of the Belle Isle tower, according to the results given above, would only exceed about one-fourth the present stability of the Planier tower ; but taking into account the great difference which the nature of the materials and the system of construction of the two edifices presents, I think it superfluous to stop for the annoying inferences to which this comparison might give rise.

Column of Boulogne-sur-mer. (Fig. 6.)

The triumphal column of Boulogne-sur-mer is, among the high towers exposed to frequent gales, one of the boldest which exist in

(13) *First state of the tower.*—The weight of the masonry of tender limestone, and of rubble of moderate sized stones, it has appeared to me ought not to be valued at more than 3372.3 lbs. per cubic yard ; hence, for 451.52 cubic yards 1522661 lbs.

Moment of horizontal resistance $1522661 \times 2.53 = 3862332.33$.

Moment of the pressure exerted by the wind $\frac{2}{3} \times 507 \times 2133.49 = 721119.62$.

Stability $= 5.3$

Present state of the tower.—Weight of the masonry $= 350.02$ cub. yd. $\times 3372.3 = 1180372.45$.

Moment of the horizontal resistance $= 1180372.45 \times 2.44 = 2880108.78$.

Moment of the pressure exerted by the wind $\frac{2}{3} \times 507 \times 1850.5 = 625469$.

Stability $= 4.6$.

Without its lantern, the Planier tower, in its present state, would have a stability equivalent to 6.0.

France. It is raised to a height of 167.54 feet, upon a plain about 160 feet above the level of the highest tides.

The total height of this monument is divided as follows:

1. Pedestal and its base	32.05	feet.
2. Base of the column	6.99	"
3. Shaft	92.68	"
4. Capital	10.32	"
5. Parapet, &c.	25.50	"
Total as given above	167.54	"

A glance at the section, *fig.* 6, is sufficient to show that the point of easiest rupture corresponds to the foot of the shaft, so that the part to consider with respect to the resistance to the action of the wind only comprises a height of 135.48 feet.

The mean exterior diameter of the shaft of the tower is 13.25 feet. In the interior is a winding staircase, with solid newell, in a well 7.15 feet in mean diameter. The diameter of the newell is 2.78 feet.

The whole of the masonry is of the choicest marble of Lunel. The shaft is divided into horizontal courses 2.65 feet rise, composed alternatively of four and eight pieces joined by wrought iron clamps 1.97 foot long by .083 foot thick. Each course corresponds to five steps, cut with their newell from a single block of stone, which engages 0.10 foot in the wall of the circular well.

The mortar of excellent quality, was made of Boulogne lime and cement of tiles.

The stability of this edifice, calculated on the same basis as that adopted for the Belle Isle tower, is only 3.5 [14]

Thus the stability of the Belle Isle tower would exceed that of the tower of Boulogne two-thirds.

This comparison must appear conclusive in favor of the design adopted for the Belle Isle light-house, since the two edifices compared are both of conical form, they are both composed of cut stone without mixture of rubble masonry, and are both elevated upon plateaux

(14) Weight of the masonry 412.28 cub. yds. $\times$ 4552.5 $=$ 1876904.7.

Moment of the horizontal resistance 1876904.7 $\times$ 1.91 $=$ 3584887.98.

Moment of the pressure $\frac{2}{3} \times 507 \times 2991.07 = 1010981.66$.

Stability $=$ 3.54.

Supposing all the voids filled, the stability of the tower of Boulogne would still be only 4.6.

equally exposed to the action of the winds. It is true, the joints are much less numerous in the column of Boulogne ; but the great rise of the courses, although certainly favorable to the solidity of their system, would have no influence against a horizontal effort sufficient to overturn it. In this respect the employment of iron cramps for the stones of the same course appears to me to be nearly useless, and only justified if the question was to resist the shaking caused by the shock of a hard body, or the shocks of waves. To increase in an efficient manner the resistance of such an edifice against the pressure of the wind by the use of iron, it would have been necessary to bind the courses together by means of anchors which would run through several courses. However, this excess of expensive precautions is entirely superfluous. In fact, it appears from researches that I owe to the kindness of M. Marguet, chief engineer of the port of Boulogne, that the column of Boulogne presents not the slightest trace of fissure, whence it must be concluded that the severest storms that it has experienced so far have in no degree compromised its stability. I will add, from the authority of several experienced mariners, that the plateau of Boulogne is exposed to gales no less violent than those which the Belle Isle light-house must bear.

Chimneys of the salt refinery of Ars, *fig.* 7 ; of the forges of Alais, *fig.* 8 ; of the steam engine of the dock of St. Ouen, *fig.* 9 ; and of the gas factory of the Faubourg Montmartre, *fig.* 10.

The five edifices which have been discussed are all situated in localities analogous to that of Belle Isle, as to the intensity of the action of the wind. It remains for me to speak of four high chimneys, only one of which is in truth exposed to gales from the sea, but the three others, although situated in the interior, nevertheless offer remarkable results by their comparison with the tower of Belle Isle.

I will cite, in the first place, *the brick chimney of the salt refinery of the village of Ars, Isle of Ré.*

This chimney is of quadrangular shape, 89.76 feet high, 11.28 feet square at the base, and 4.49 feet square at the top. The thickness of the walls is 2.92 feet at the base, and is reduced to 1.48 foot at the top by four offsets of 0.36 foot each. The chimney of Ars is contained in the building of the refinery about 30 feet, so that it is only subjected to the action of the wind above this height. It was built in 1825, and it appears from authentic documents collected by M. Potel,

civil engineer at La Rochelle, that since that time the island of Ré has experienced several remarkably violent gales, the action of which is fully developed against an edifice wholly unmasked on all sides.

If we admit that the section of easiest rupture corresponds to the level of the ceiling of the refinery, and that a cubic yard of brick work weighs 2529 pounds, we will find for the stability of the chimney of Ars 1.66. (15.) So the stability of the Belle Isle light-house would be equal to $3\frac{1}{2}$ times that of this chimney—a result no less decisive than that which the Pilier light-house has furnished.

I will cite, in the second place, *the chimney of the forges and foundries of Alais*, department of the Gard. From a design, and different accounts, the communication of which I owe to the kindness of M. Berard, director-general of bridges and roads and of mines, this chimney, which, according to the design, was to have been 195.86 feet high, has only been built 180.43 feet high. Its form is a truncated cone, the two bases of which are respectively 20.99 feet and 7.70 feet in diameter. The thickness of its circular wall is 4.92 feet at the base, and is reduced to .81 foot at the top. Four offsets have been made in the interior face of the wall. The first offset is 1.08 foot, and is made at a height of 48.88 feet. The three others are 0.41 foot each, and are made every 32.80 feet. The space comprised between the ground and the first offset is cylindrical, so that the thickness of the wall is variable through that height, but for the remainder of the height of the shaft the interior faces are parallel to the exterior ones.

This chimney is built of brick, except a base 9.84 feet high, which is built of cut stone.

It is easy to assure ourselves, by a preliminary approximate calculation, that the point of easiest rupture is situated just above the mass of cut stone, so that, with reference to stability, we have only to consider the part constructed of bricks.

(15.) Moment of the resistance 113.97 cubic yards $\times$ 2529 $\times$ 1.64 = 472680.8.
Moment of the pressure exerted by the wind 23.23 $\times$ 2.38 $\times$ 10.23 $\times$ 507 = 282604.8.
Stability = 1.66.

I have supposed, to simplify the calculation, the chimney unmasked to the level of the ceiling, which does not sensibly affect the value of the stability that would have been found considering only the part above the roof.

Admitting, as in the preceding article, that a cubic yard of brick-work weighs 2529 pounds, I have found the stability of this chimney equivalent to 1.76.(16)

Thus it does not attain the one-third of the stability of the Belle Isle light-house.

The chimney of the forges of Alais, being of recent construction, has probably not yet sustained the maximum of effort to which it may be exposed by the action of the winds; but it is to be presumed that this last proof will not be waited for long, as all of the eastern part of Languedoc annually experiences tempests which are of extreme violence. This edifice is, besides, completely isolated and unmasked, and the gales which it has borne during two equinoxes have not occasioned the slightest fissures in the masonry.

The chimney of the steam engine of the dock of St. Ouen is also of recent construction; but it is isolated in a plain where storms of great severity occur, and it offers a remarkable example of a construction truly bold.

Its total height is 133.19 feet, a pedestal of 1.97 foot in height included. It is a quadrangular truncated pyramid, 10.17 feet square above the base, and 3.61 feet square at the foot of the cornice.

The thickness of the wall is 2.46 feet at the level of the base, reduced to 0.82 foot at the top by five offsets at every 21.32 feet.

The base is built of hard cut stone. The body of the chimney is of brick, and the capital is a single piece of cast iron, weighing 2205 pounds.

From these given quantities, I have found that the stability of the chimney of the steam engine of St. Ouen can be represented by 0.87.(17) That is, the moment of the horizontal resistance of this edifice is inferior to the moment of the pressure which I have considered as representing the maximum of the force of the wind.

Thus, leaving out of consideration the adhesion of the mortar in

(16) Moment of the resistance, 519.28 cub. yd. $\times$ 2529 $\times$ 2.9 = 3808450.1.

Moment of the pressure exerted by the wind = $\frac{2}{3} \times 507 \times 265.15 \times 24.09 = 2158962.7$.

Stability = 1.76.

If the chimney of the forges of Alais had been raised to the height originally designed, its stability would have been reduced to 1.60.

(17) Moment of the resistance (184.04 cub. yd. $\times$ 2529 + 2205.5) $\times$ 1.7 = 794992.42.

Moment of the pressure exerted by the wind, 1798.63 $\times$ 507 = 911805.4.

Stability = 0.866.

the whole extent of the section of rupture, it must be acknowledged that a storm exerting a pressure of 507 pounds per square yard, upon one of the faces of the chimney in question, would infallibly overturn it. Hence, when it shall have borne without accident the action of the most violent winds which are ever experienced in our country, it will be demonstrated that this pressure may be considered greater than the maximum effort of our hurricanes. We see, besides, from this same result, that the stability of the chimney of the dock of St. Ouen is not equal to one-sixth of the stability of the Belle Isle light-house.

To reproduce an example cited by the author of the design of that light-house, I have considered that I ought to complete these comparisons by the determination of the stability *of the chimney of the gas factory of the Faubourg Montmartre*, situated upon one of the highest points in Paris.

This chimney, built of brick, is 85.29 feet high above the point of easiest rupture; a basement 13.12 feet high not included.

It presents the form of a square truncated pyramid, 8.20 feet square at the base, and 4.92 feet square at the top. The thickness of the wall diminishes from 1.64 foot to 0.82 foot, by means of the two offsets, each 0.41 foot.

I have found that the stability of this edifice may be represented by 0.71.[18] So that it scarcely attains one-eighth of the stability of the Belle Isle tower.

Conclusion.

The results of the calculations and comparisons that I have presented may be shown in the following table, where the numbers expressing the absolute stabilities of the edifices are placed by the side of those expressing the relative stabilities, calculated by taking the stability of the tower of Belle Isle for a unit.

(18) Moment of the resistance 85.02 cubic yards $\times$ 2529 $\times$ 1.36 = 292352.4.
Moment of the pressure exerted by the wind 63.27 square yard $\times$ 12.97 $\times$ 507 = 416039.
Stability = 0.71.

	Stabilities.	
	Absolute.	Relative.
Signal tower of L'Orient. *Fig.* 1	7.4	1.28
Light-house of Genoa. *Fig.* 2	6.2	1.07
Light-house of Belle Isle (with partition wall 1.97 foot thick.) *Fig.* 3	5.8	1.00
Light-house of the Pilier (near Noirmoutier island. *Fig.* 4	4.4	0.76
Light-house of Planier (near Marseilles.) *Fig.* 5	4.6	0.79
Column of Boulogne. *Fig.* 6	3.5	0.60
Chimney of the salt refinery of Ars. *Fig.* 7	1.64	0.28
Chimney of the forges and foundries of Alais, (Gard.) *Fig.* 8	1.76	0.30
Chimney of the steam engine of the dock of St. Ouen. *Fig.* 9	0.87	0.15
Chimney of the gas factory of the Faubourg Montmartre. *Fig.* 10	0.71	0.12

This table, joined to the comparison represented on the plate, appears to me to offer a superabundance of proofs which ought to dispel all doubts raised upon the stability of the Belle Isle light-house, as to the resistance which it should oppose to the efforts of the wind.

Of the nine edifices taken for terms of comparison, two, it is true, the tower of L'Orient and that of Genoa, presents a stability superior to that of this light-house, and a third, the Planier tower, has been somewhat damaged; but the very economical system of their construction is so inferior in true solidity to that of the tower designed for Belle Isle, that these three comparisons cannot weaken the consequences resulting from the other terms of comparison. I will even add that the example drawn from the two first edifices must appear very encouraging, since they are but little superior in horizontal resistance to that tower, and their long and perfect preservation shows an evident excess of stability.

The tower of Boulogne, superior to that of Belle Isle in nicety of cutting, is otherwise so inferior in horizontal resistance, that this single example may appear sufficient to decide the question.[19]

The Pilier light-house, inferior to that of Belle Isle with respect both to stability and the system of construction, offers a comparison to which there is only wanting to make it as conclusive as that of the column of Boulogue, the guarantees resulting from a longer proof.

(19) M. Lamblardie, in his report to the general eouneil of bridges and roads upon different modifications of the approved design of the Belle Isle light-house proposed by the engineers charged with its exeeution, has insisted particularly upon the consequenees resulting from the comparison of this design with the tower of Boulogne.

It might be objected that these same guarantees are also wanting in the examples drawn from the brick chimneys of Ars, Alais, St. Ouen, and the Faubourg Montmartre, and that, besides, three of these chimneys are situated in localities where the wind does not blow with the same violence as at Belle Isle. It may be answered as to the objection founded on the fact that these four edifices have not long existed, that England has contained, for more than twenty years, a considerable number of chimneys as light as these, which have served as models for constructions of this kind executed in France. I will agree that the localities where they are situated are generally less exposed to the wind than the high plateaux of Belle Isle, but I am firmly of the belief that the real intensity of the winds which prevail at sea is exaggerated by confounding their *frequency* with their *violence*. At the surface of the sea, the motions of the lower layers of the atmosphere are propagated, it is true, with more facility and uniformity than upon land, but it does not follow that tempests are always more violent on the sea than on the land, or in other words, that any point whatever of the continents cannot experience in a longer or shorter interval hurricanes quite as terrible as any point whatever of the surface of the sea situated under the same parallel. The frequent examples of trees broken down or torn up in the interior of the country prove what energy the wind can develop there. Doubtless, cases of masonry edifices thus overturned are a great deal more rare. As I have already observed, it is to unequal settling resulting from a bad establishment of the foundations, to a defect in homogenity and bond of the masonry, or to a defect in the resistance of the materials, that must be attributed nearly the whole of the damages sustained by edifices of great elevation. It therefore would be vain to increase their apparent stability, if their system of construction was essentially vicious, or if the workmanship was neglected. But none of these causes of destruction or of damage appear to be feared for the Belle Isle light-house, founded upon an incompressible soil and designed to be entirely of cut stone, and it cannot be doubted that the success of its construction will be fully assured by an active superintendence and a continual exaction of the execution of the clauses of the specifications.

THE END.

DATE DUE

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